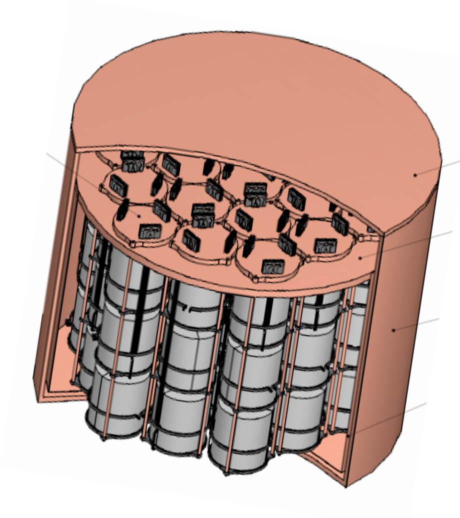
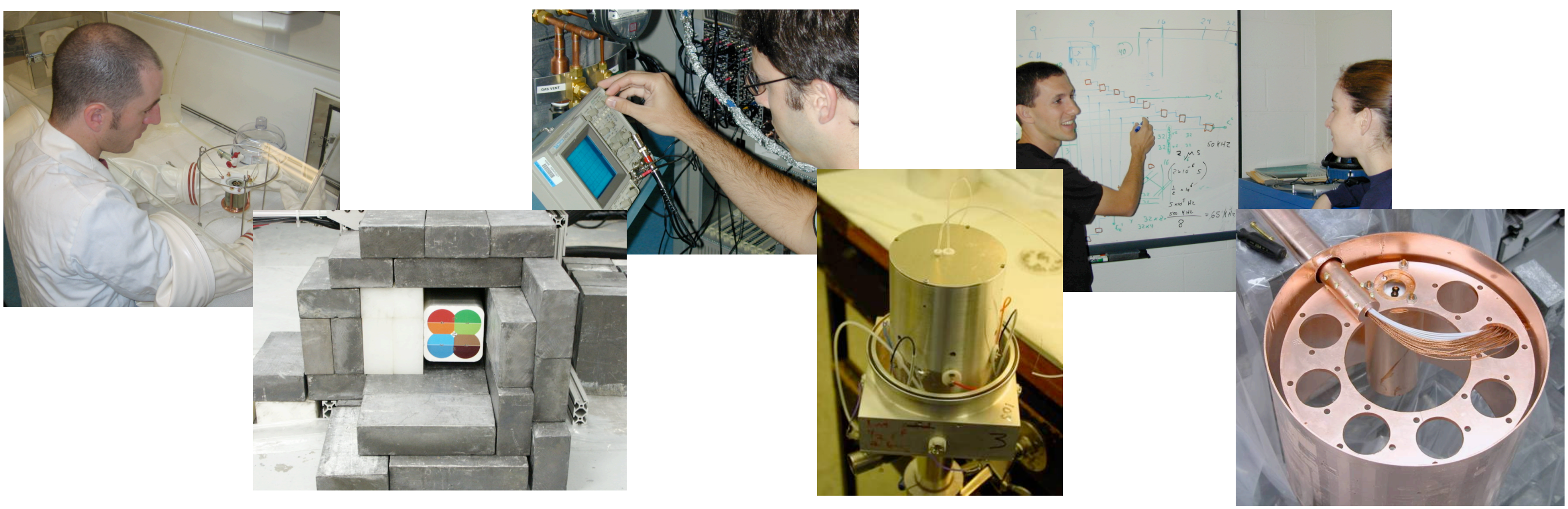
The *Majorana* 0νββ-decay Experiment

- Introduction
- Majorana Overview
- Sensitivity
- Status and Summary





J.F. Wilkerson
on behalf of the *Majorana* Collaboration

October 29, 2005

PANIC Satellite Neutrino Planning Workshop

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Note: Red text indicates students

Advantages for Majorana

^{76}Ge offers an excellent combination of capabilities and sensitivities. Majorana is preparing to proceed, with demonstrated technologies.

- Favorable nuclear matrix element $\langle M'^{0\nu} \rangle = 2.4$ [Rod05].
- Reasonably slow $2\nu\beta\beta$ rate ($T_{1/2} = 1.4 \times 10^{21}$ y).
- Demonstrated ability to enrich from 7.44% to 86%.
- Ge as source & detector.
- Elemental Ge maximizes the source-to-total mass ratio.
- Intrinsic high-purity Ge diodes.
- Excellent energy resolution — 0.16% at 2.039 MeV
- Powerful background rejection.
  Segmentation, granularity, timing, pulse shape discrimination
- Best limits on $0\nu\beta\beta$ - decay used Ge (IGEX & Heidelberg-Moscow)
  $T_{1/2} > 1.9 \times 10^{25}$ y (90%CL)
- Well-understood technologies
  - Commercial Ge diodes
  - Large Ge arrays (GRETINA, Gammasphere)

The Majorana Scientific Goals

Search for neutrinoless double-beta decay in ^{76}Ge

- Definitively test the Klapdor-Kleingrothaus ^{76}Ge claim in the 400 meV region ($T_{1/2} = 1.2 \bullet 10^{25}$ y).
- Probe the quasi-degenerate neutrino mass region of 100 meV.
- Demonstrate backgrounds that would justify scaling up to a 1-ton or larger detector.

The Majorana 180 kg Experiment Overview

The 180 kg Experiment (M180)

- Reference Design
  - 171 segmented, n-type, 86% enriched ^{76}Ge crystals.
  - 3 independent, ultra-clean, electroformed Cu cryostat modules.
  - Enclosed in a low-background passive shield and active veto.
  - Located deep underground (6000 mwe).
- Background Specification in the $0\nu\beta\beta$ peak ROI (4 keV at 2039 keV)

  1 count/t-y
- Expected Sensitivity to $0\nu\beta\beta$ (for 3 years, or 0.46 t-y of ^{76}Ge exposure)

  $T_{1/2}$ >= 5.5×10^{26} y (90% CL)

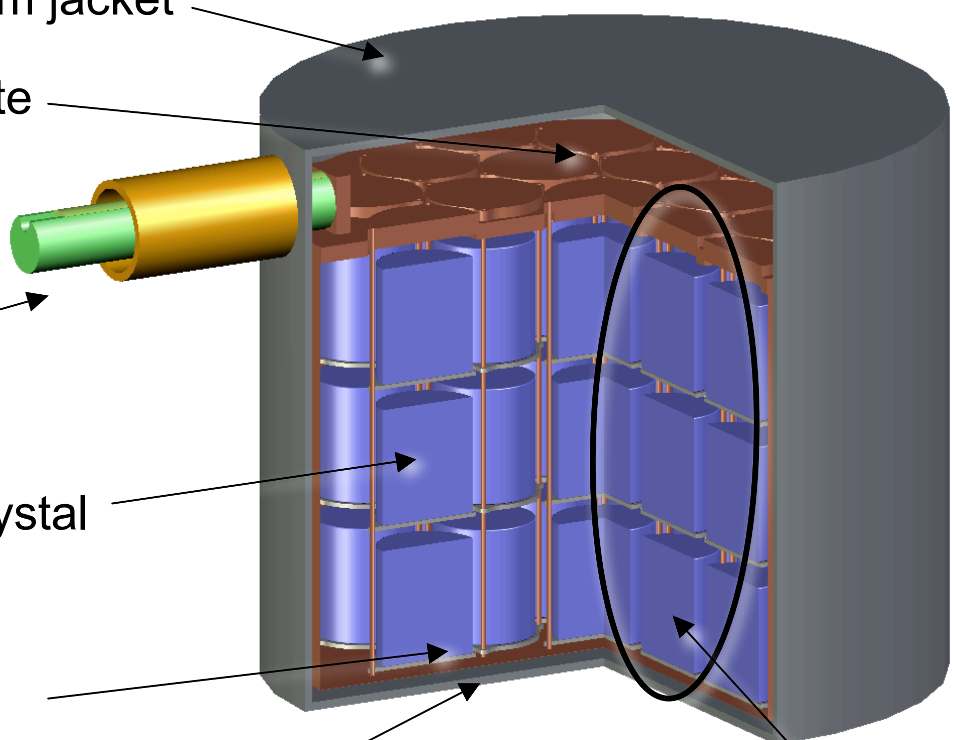
  $\langle m_\nu \rangle$ < 100 meV (90% CL) ([Rod05] RQRPA matrix elements)

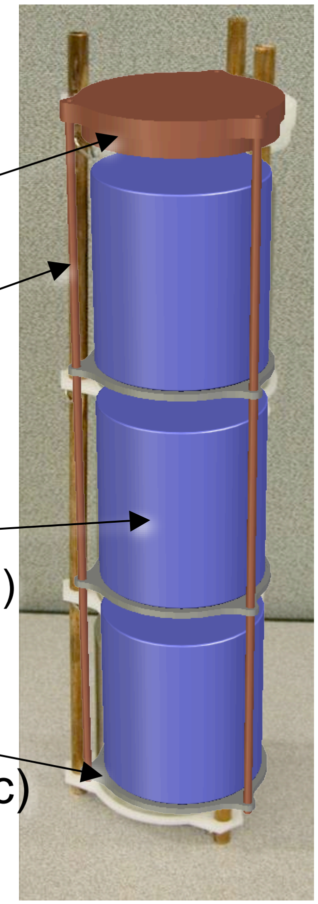
  or a 10% measurement assuming a 400 meV value.

Majorana is scalable, allowing expansion to 1000 kg.

The Majorana Modular Approach

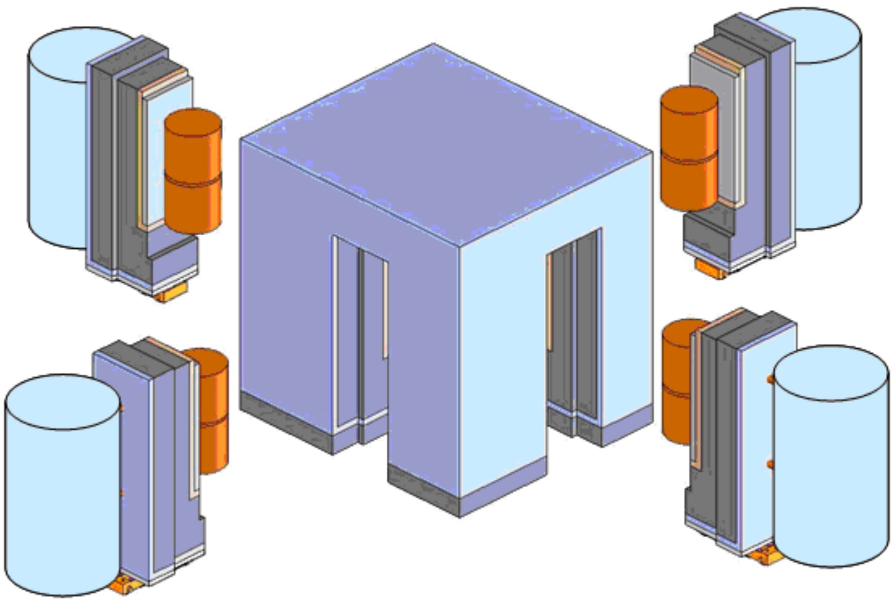
- 57 crystal module
  - Conventional vacuum cryostat made with electroformed Cu.
  - Three-crystal stack are individually removable.



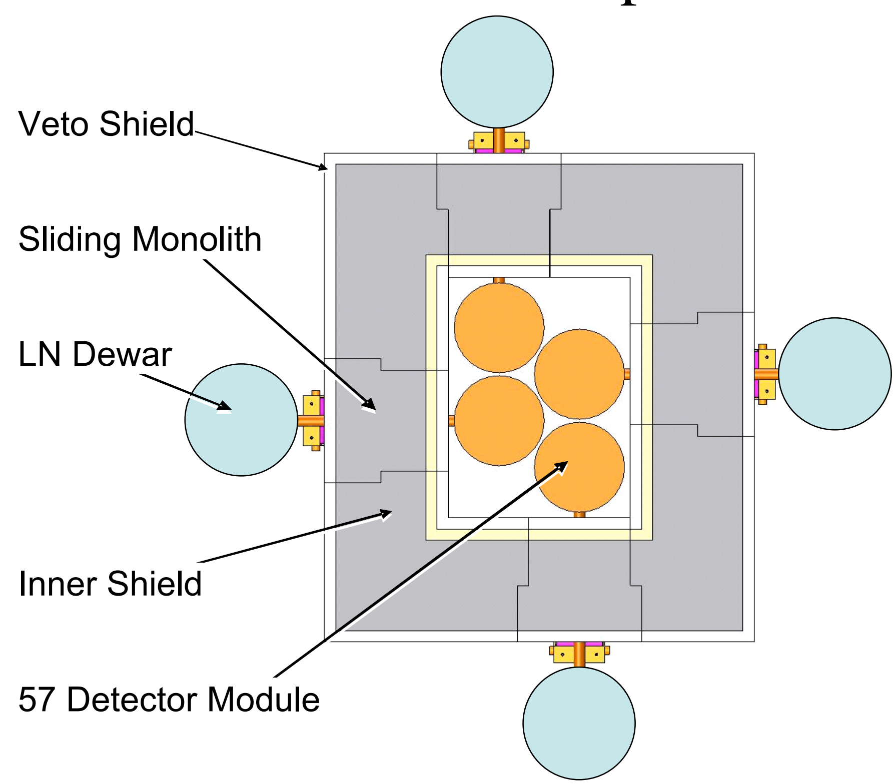


The Majorana Shield - Conceptual Design

- Allows modular deployment, early operation
- contains up to eight 57-crystal modules
  (M180 populates 3 of the 8 modules)
- four independent, sliding units
- 40 cm bulk Pb, 10 cm ultra-low background shield
- active 4π veto detector



Top view



Reducing Backgrounds - Two Basic Strategies

- Sensitivity to $0\nu\beta\beta$ decay is ultimately limited by S-to-B.
- Directly reduce intrinsic, extrinsic, & cosmogenic activities
  - Select and use ultra-pure materials
  - Minimize all non "source" materials
  - Clean passive shield
  - Go deep — reduced μ's & related induced activities
- Utilize background rejection techniques
  - Energy resolution
    - $0\nu\beta\beta$ is a single site phenomenon
    - Many backgrounds have multiple site interactions
  - Granularity [multiple detectors]
  - Single Site Time Correlated events (SSTC)
  - Active veto detector
  - Pulse shape discrimination (PSD)
  - Segmentation

Demonstrating Backgrounds

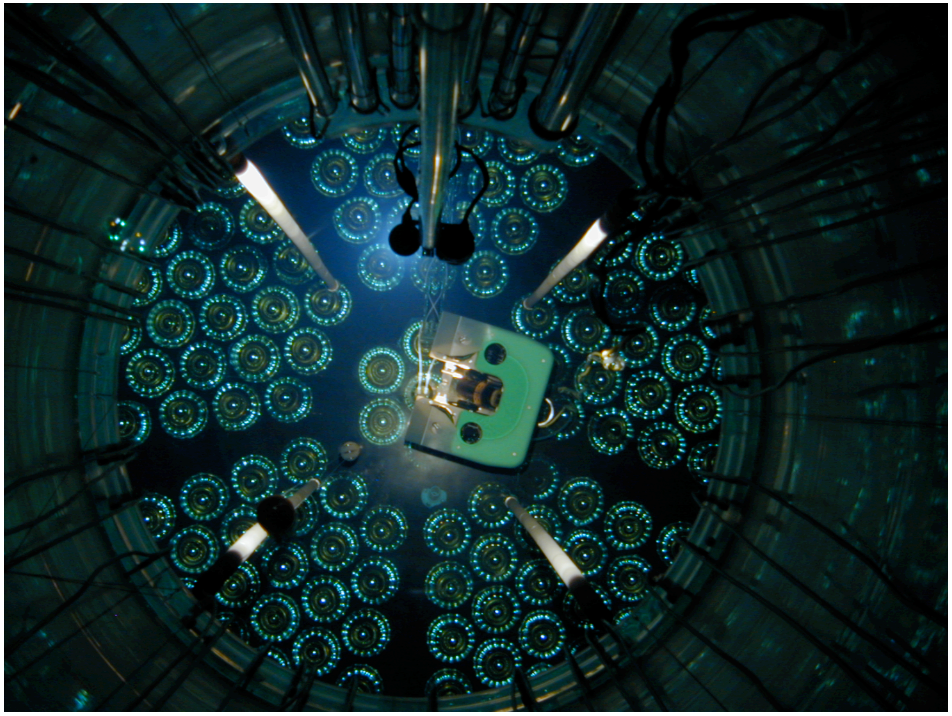
- **Simulations**
  - MaGe – GEANT4 based development package
    - being developed in cooperation with GERDA
  - Verified against a variety of Majorana low-background counting systems as well as others, e.g. MSU Segmented Ge, GERDA.
  - Fluka for μ-induced calculations, tested against UG lab data.
- **Assay**
  - Radiometric (Current sensitivity ~8 μBq/kg (2 pg/g) for ^{232}Th)
    - Counting facilities at PNNL, Oroville (LBNL), WIPP, Soudan, Sudbury.
  - Mass Spect. (Current sensitivity 2-4 μBq/kg (0.5-1 pg/g) for ^{232}Th)
    - Using Inductively Coupled Plasma Mass Spectrometry, have made recent progress on using ^{229}Th tracer.
    - ICPMS has the requisite sensitivity (fg/g).
    - Present limitations on reagents being addressed by sub-boiling distillation.
    - ICPMS expected to reach needed 1 μBq/kg sensitivity.

- **Key specifications**
  - Cu at 1 μBq/kg (current ≤ 8 μBq/kg)
  - cleanliness on a large scale (100 kg)

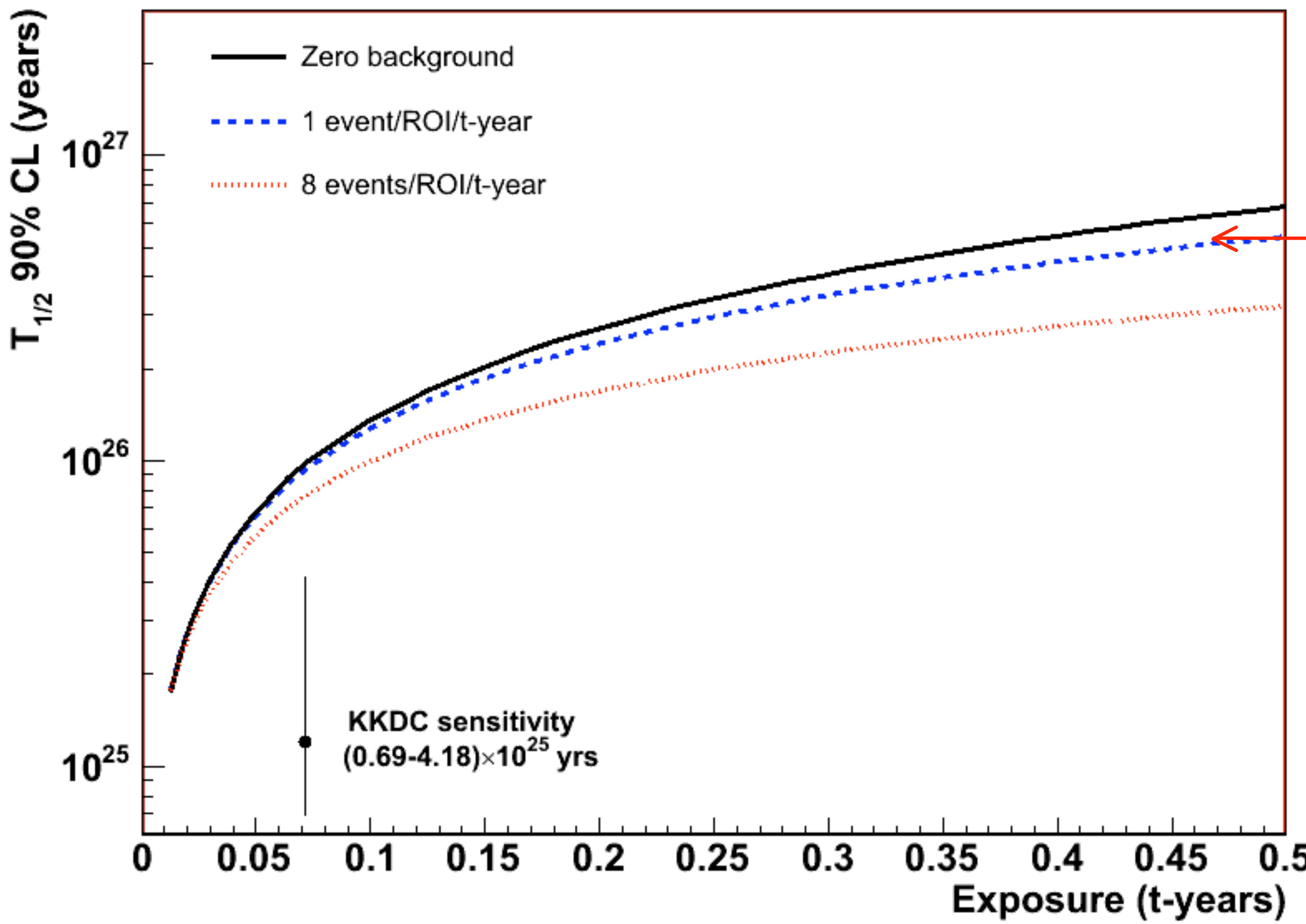
Background reduction at the larger scale

- The collaboration has groups experienced with building 2-10 kg level $0\nu\beta\beta$ decay experiments: IGEX, ELEGANT, NEMO, ^{82}Se
- The collaboration has groups experienced with building low-background, large-scale detectors underground: SNO, KamLAND, SAGE
- SNO Acrylic Sphere, 30 t, 120 segments, < 2 μBq/kg ^{232}Th

- SNO Neutral Current Detector Array of ^{3}He proportional counters
  - –450 kg of material
  - –300 detector segments
  - –Activity 100 - 1000 times cleaner than best previous counters
  - –Activity: <= 4 ppt ^{238}U
    <= 7 ppt ^{232}Th



Majorana Sensitivity vs. Background



$<m_\nu>$
of
100 meV
[Rod05]

The KKDC Result

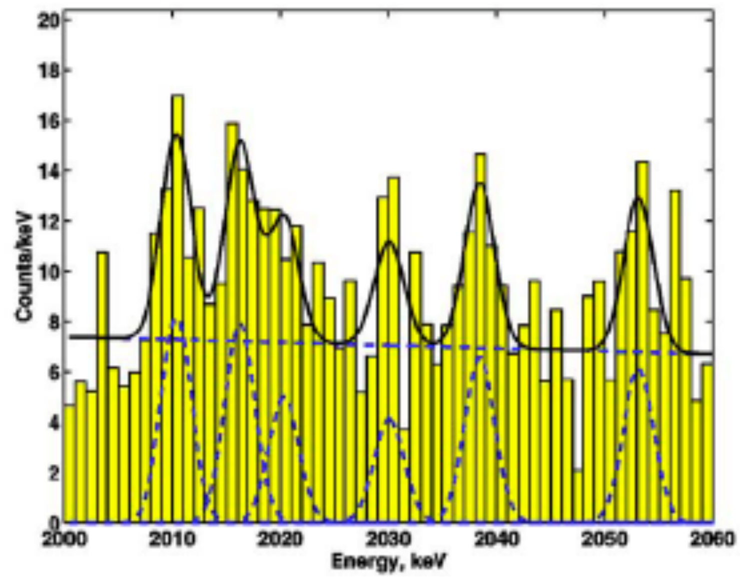
Klapdor-Kleingrothaus H V, Krivosheina I V, Dietz A and Chkvorets O, *Phys. Lett.* B **586** 198 (2004).

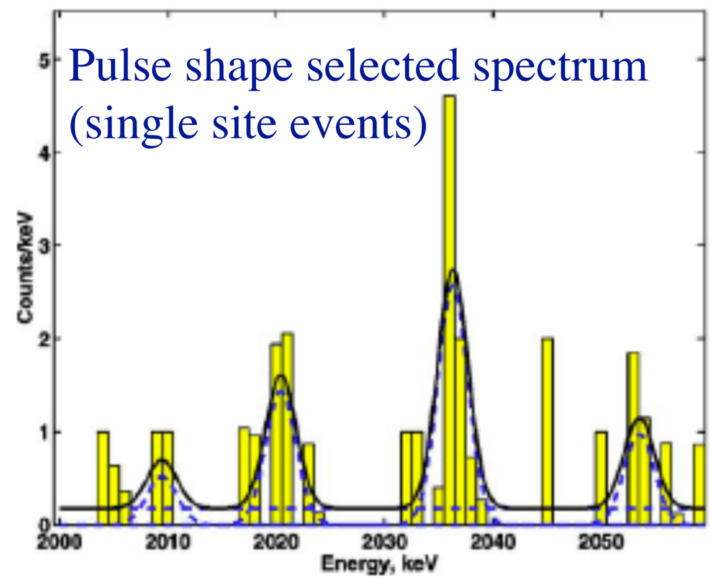
Best result - 5 ^{76}Ge crystals, 10.96 kg of mass, 71 kg-years of data.

$T_{1/2} = (1.19 +2.99/-0.5\ ) \times 10^{25}$ y
$0.24 < m_\nu < 0.58$ eV (3 sigma)

Plotted a subset of the data for four of five crystals, 51.4 kg-years of data.

$T_{1/2} = (1.25 +6.05/-0.57) \times 10^{25}\ y$





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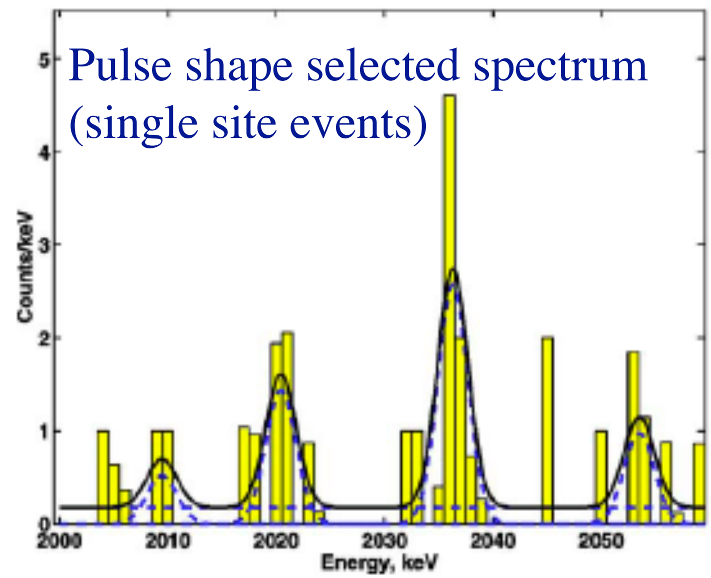
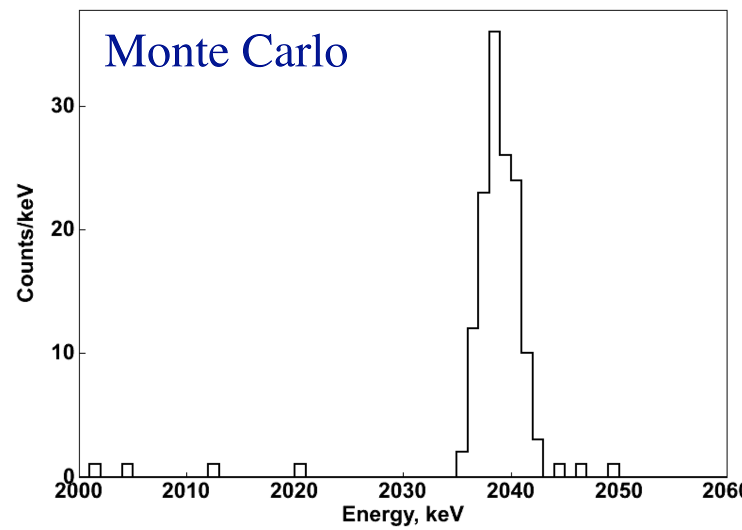


Expected signal in Majorana
After cuts (for 0.46 t-y)

135 counts

With a background of

Specification: < 1 total count in the ROI



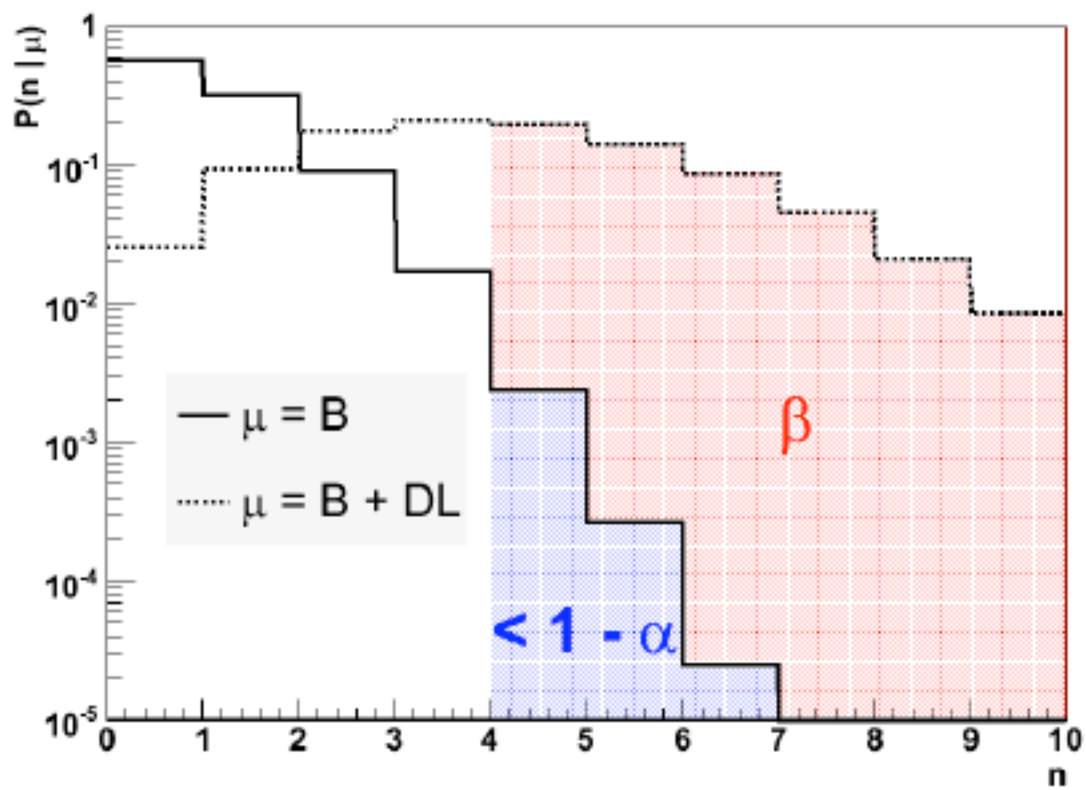
Neutrino Scientific Assessment Group

Recommendation: *The Neutrino Scientific Assessment Group recommends that the highest priority for the first phase of a neutrino-less double beta decay program is to support research in two or more neutrino-less double beta decay experiments to explore the region of degenerate neutrino masses* ($\langle m_{\beta\beta}\rangle > 100$ meV)*. The knowledge gained and the technology developed in the first phase should then be used in a second phase to extend the exploration into the inverted hierarchy region of neutrino masses* ($\langle m_{\beta\beta}\rangle > 10-20$ meV) *with a single experiment*.

Majorana: The excellent background rejection achieved from superior energy resolution in past ^{76}Ge experiments must be extended using new techniques. The panel notes with interest the communication between the Majorana and GERDA ^{76}Ge experiments which are pursuing different background suppression strategies. The panel supports an experiment of smaller scope than Majorana-180 that will allow verification of the projected performance and achieve scientifically interesting physics sensitivity, including confirmation or refutation of the claimed ^{76}Ge signal. A larger ^{76}Ge experiment is a good candidate for a larger international collaboration due to the high cost of the enriched isotope.

Majorana Sensitivity vs. Discovery Level

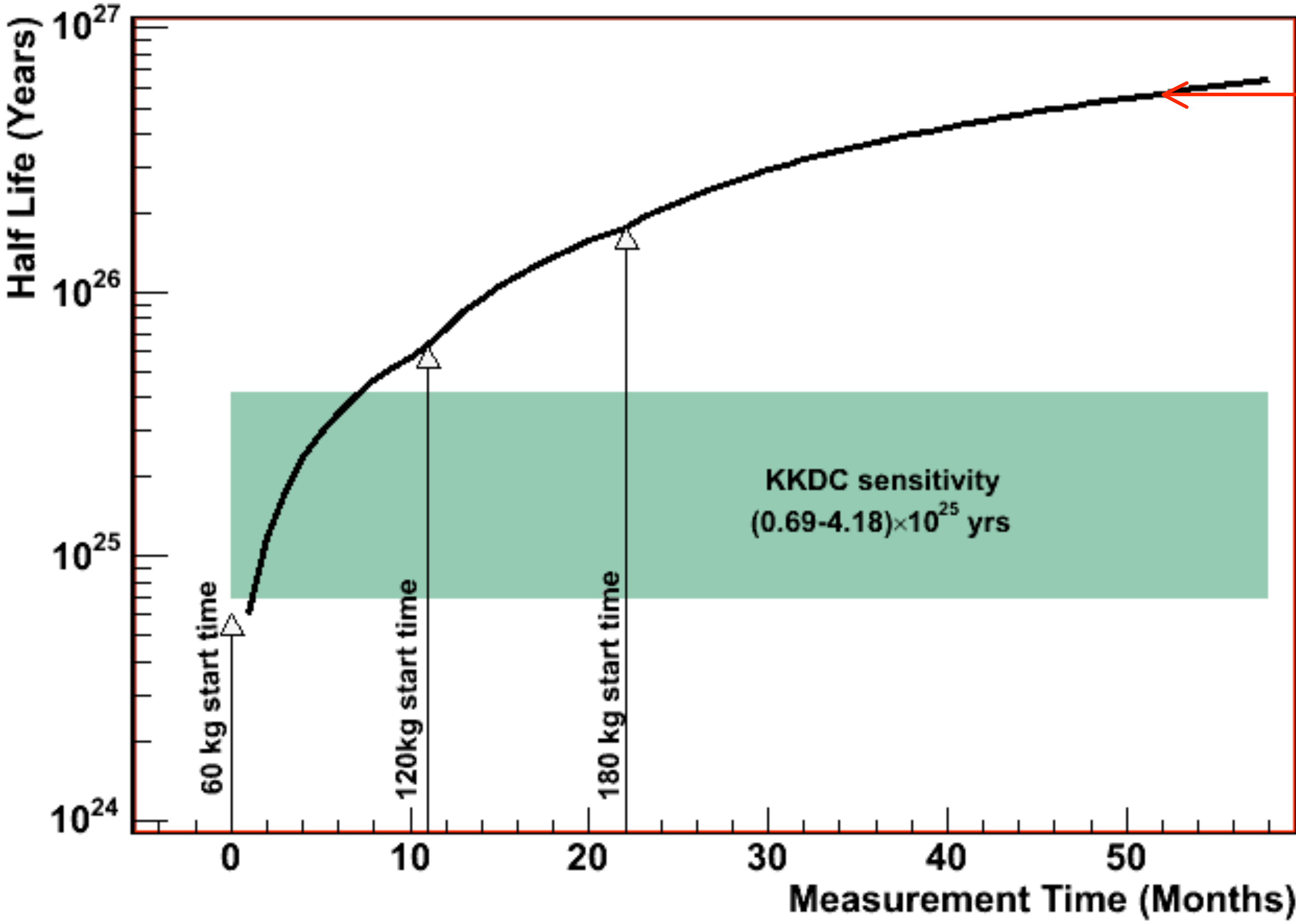
	M60		M120		M180	
	$T_{1/2}$ $[10^{26}\ \mathrm{y}]$	$\langle m_{\beta\beta}\rangle$ [meV]	$T_{1/2}$ $[10^{26}\ \mathrm{y}]$	$\langle m_{\beta\beta}\rangle$ [meV]	$T_{1/2}$ $[10^{26}\ \mathrm{y}]$	$\langle m_{\beta\beta}\rangle$ [meV]
sensitivity (90% CL)	2.1	200	3.9	150	5.6	120
3σ DL ($\beta = 0.5$)	2.2	200	3.3	160	5.2	130
3σ DL ($\beta = 0.9973$)	0.55	390	0.94	300	1.4	240



In the figure
$B = 0.56$
$\alpha = 0.9973$ ($3\ \sigma$)
$\beta = 0.5$,
giving DL = 3.1.

Currie, Anal. Chem. **40**, 586 (1968)

Majorana M180 Sensitivity



$\langle m_\nu \rangle$ of 100 meV [Rod05]

Current Status

Working towards generating a revised proposal for DOE.

- Continuing R&D
  - Electroforming of Cu underground (WIPP and Soudan)
  - Segmented detector studies.
  - Developing a testbed for prototyping Majorana cryostat design, shielding, contacts, materials, and detector readout options.
  - **LArGe**, the use of liquid Argon as an ultra-clean active shield.
- Review of our "reference plan"
  - Segmentation benefits and risks.
- Background studies
  - Nearing completion of a comprehensive review of our anticipated backgrounds.
  - Performing a careful simulation of realistic parts and materials
  - Materials Sampling with radiometric and ICP-MS techniques.
- Bottom's up WBS and costing exercise.
  - (Joint UW-PNNL)
  - Potential to be cleaner than the shielding materials currently specified in the Majorana reference design, may be important for 1000 kg experiment.

Majorana Summary

- The Majorana design is scalable to the 1000 kg level.
- Compared to best previous $0\nu\beta\beta$ experiments, M180
  - has 18 times more Ge
  - 8 times lower radioactivity
  - Improved design and detector technology should yield 30 times better background rejection.
- With M180 we can reach a lifetime limit of 5.5×10^{26} y (90% CL) corresponding to a neutrino mass of 100 meV or perform a 10% measurement assuming a 400 meV value.
- Ready to submit our proposal to DOE in 1st quarter 2006.

For more detailed documents see:

http://ewiserver.npl.washington.edu/majorana/NuSAG/documents.html